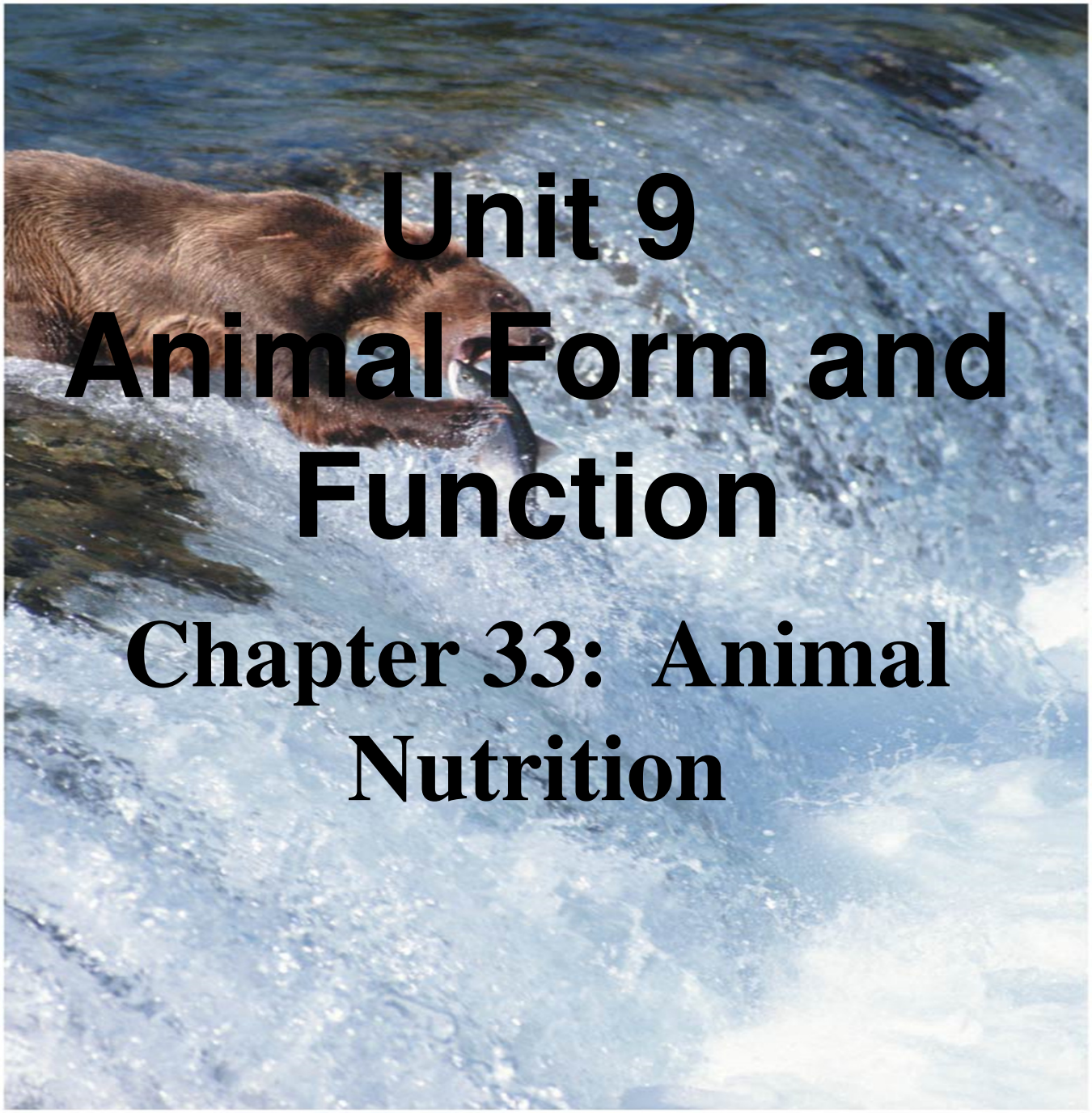


Unit 9
Animal Form and Function

Chapter 33: Animal Nutrition

Overview: The Need to Feed

- Food is taken in, taken apart, and taken up in the process of animal **nutrition**
- In general, animals fall into three categories
  - **Herbivores** eat mainly plants and algae
  - **Carnivores** eat other animals
  - **Omnivores** regularly consume animals as well as plants or algae
- Most animals are also opportunistic feeders
- Animals must balance their consumption, storage, and use of food

Concept 33.1: An animal's diet must supply chemical energy, organic molecules, and essential nutrients

- An animal's diet provides
  - Chemical energy, which is converted into ATP to power cellular processes
  - Organic building blocks, such as organic carbon and organic nitrogen, to synthesize a variety of organic molecules
  - **Essential nutrients**, which are preassembled organic molecules and minerals required by cells

Essential Nutrients

- **Essential nutrients** must be obtained from an animal's diet
  - Serve as substrates, coenzymes, and cofactors
- There are four classes of essential nutrients
  - Essential amino acids
  - Essential fatty acids
  - Vitamins
  - Minerals

Essential Fatty Acids and Amino Acids

- In animals, fatty acids are converted into a variety of cellular components, such as membrane phospholipids, signaling molecules, and storage fats
  - **Essential fatty acids** can be synthesized by plants
- Animals require 20 amino acids and can synthesize about half from molecules in their diet
  - The remaining amino acids, the **essential amino acids**, must be obtained from food in preassembled form

Vitamins and Minerals

- **Vitamins** are organic molecules required in the diet in small amounts
- **Minerals** are simple inorganic nutrients, usually required in small amounts
  - Ingesting large amounts of some minerals can upset homeostatic balance
  - Ex: Excess salt can contribute to high blood pressure

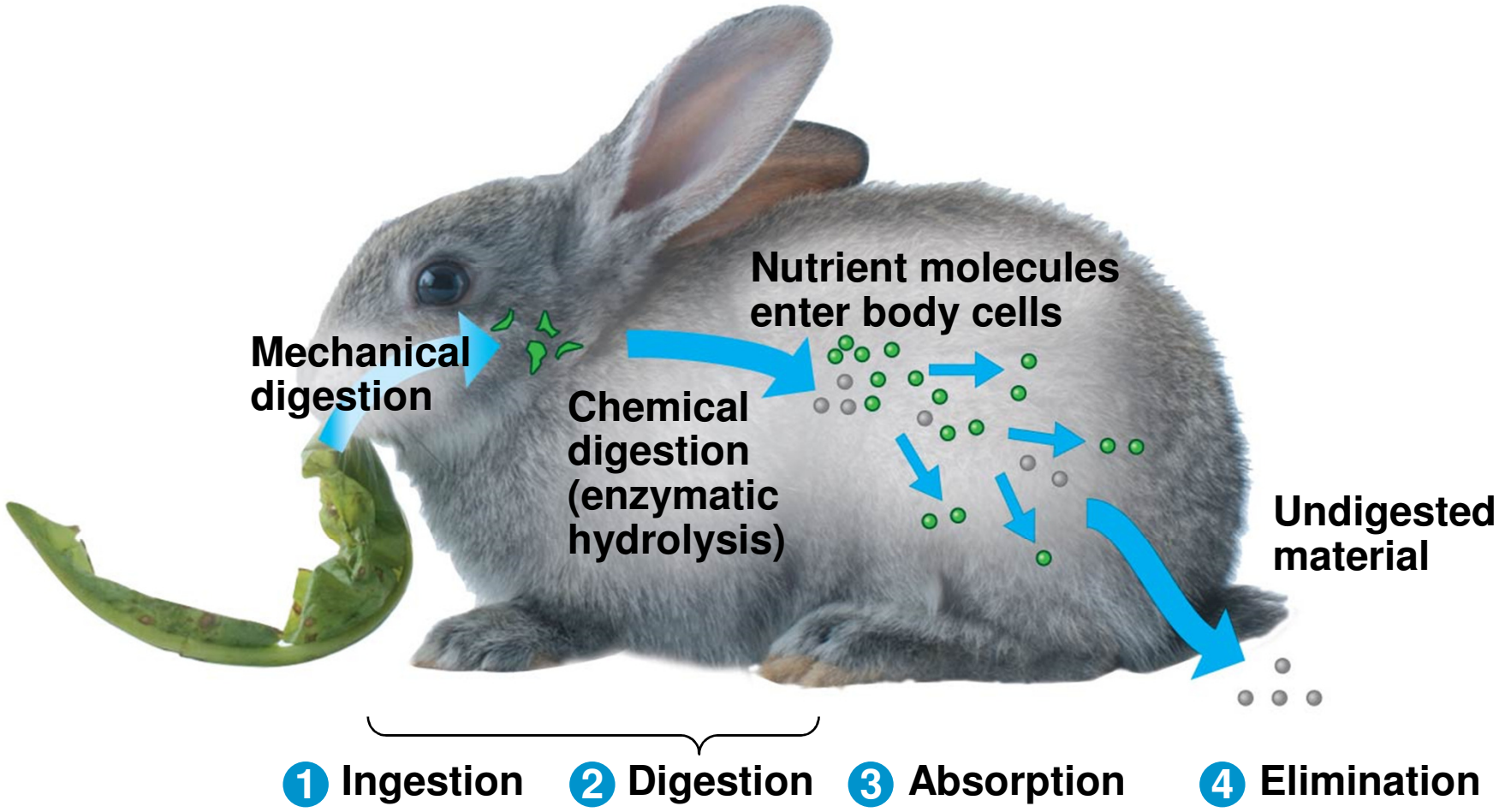
Dietary Deficiencies

- *Malnutrition* results from the long-term absence from the diet of one or more essential nutrients
- *Undernutrition* results when a diet does not provide enough chemical energy
  - Use up stored fat and carbohydrates
  - Break down its own proteins
  - Lose muscle mass
  - Suffer protein deficiency of the brain
  - Die or suffer irreversible damage

Concept 33.2: The main stages of food processing are ingestion, digestion, absorption, and elimination

- Food processing can be divided into four distinct stages
  1. **Ingestion** is the act of eating or feeding
  2. **Digestion** is the process of breaking food down into molecules small enough to absorb
  3. **Absorption** is uptake of nutrients by body cells
  4. **Elimination** is the passage of undigested material out of the digestive system

Figure 33.4


Mechanical digestion
Chemical digestion (enzymatic hydrolysis)
Nutrient molecules enter body cells
Undigested material
1 Ingestion
2 Digestion
3 Absorption
4 Elimination

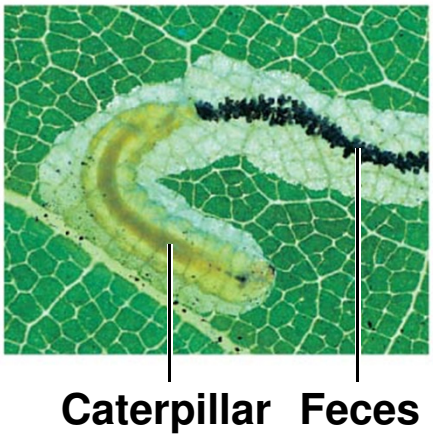
Ingestion

- Strategies for extracting resources from food differ widely among animals
  - *Filter feeders*: Strain small organisms or food particles
  - *Substrate feeders*: Live in or on their food source
  - *Fluid feeders*: Suck nutrient-rich fluid from a living host
  - *Bulk feeders*: Eat relatively large pieces of food
    - Includes humans

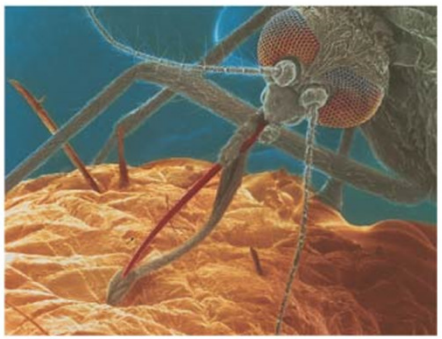
Figure 33.5

Filter feeders

Substrate feeders



Fluid feeders



Bulk feeders

Digestion

- Mechanical digestion, including chewing, increases the surface area of food
- Chemical digestion splits food into small molecules that can pass through membranes
  - *Enzymatic hydrolysis* splits bonds in molecules with the addition of water

Digestive Compartments

- Most animals process food in specialized compartments
  - Can be intracellular compartments
    - Food vaculoles
  - Or extracellular
    - Digestive organs and system
- These compartments reduce the risk of an animal digesting its own cells and tissues

Intracellular vs Extracellular Digestion

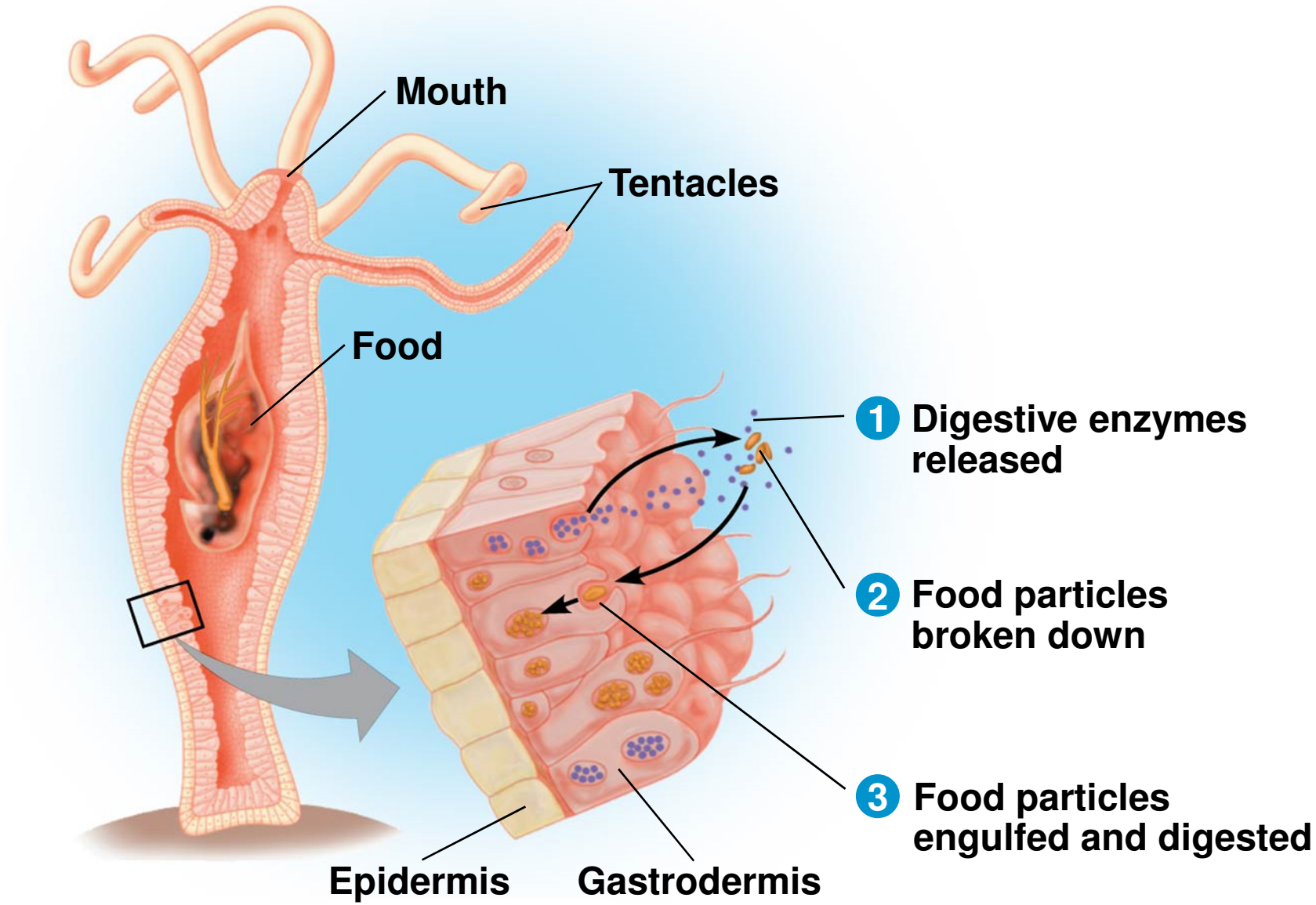
- In intracellular digestion
  - Food particles are engulfed by phagocytosis
  - Liquid is ingested by pinocytosis
- Food vacuoles fuse with lysosomes containing hydrolytic enzymes

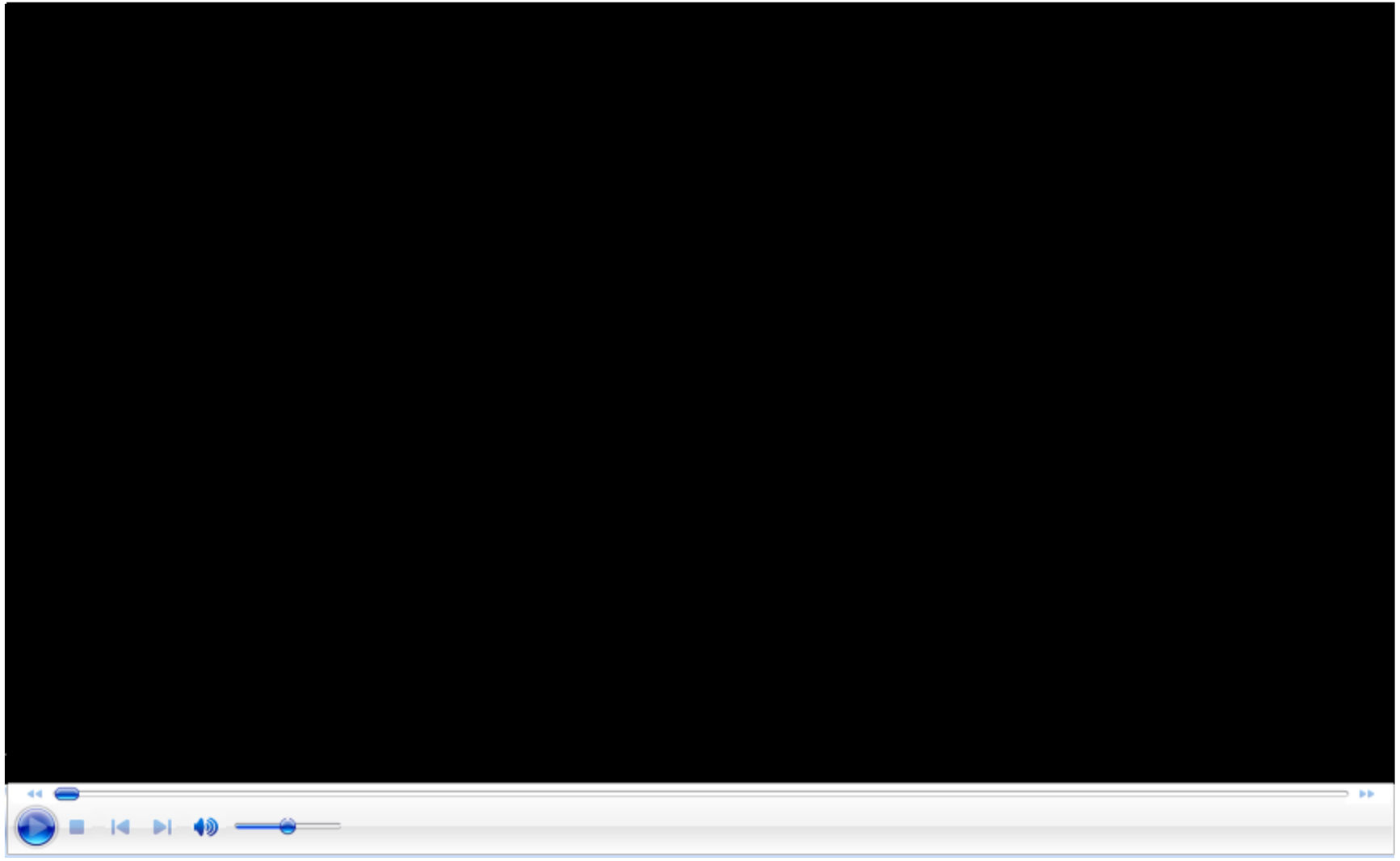
- Extracellular digestion is the breakdown of food particles outside of cells
  - It occurs in compartments that are continuous with the outside of the animal's body

Extracellular Digestion

- Animals with simple body plans have a **gastrovascular cavity** that functions in both digestion and distribution of nutrients
  - Ex: Cnidarians and flatworms
- More complex animals have a complete digestive tract, or **alimentary canal**, with a mouth and an anus
  - Food moves along the alimentary canal in a single direction
  - Can have specialized regions that carry out digestion and absorption in a stepwise fashion

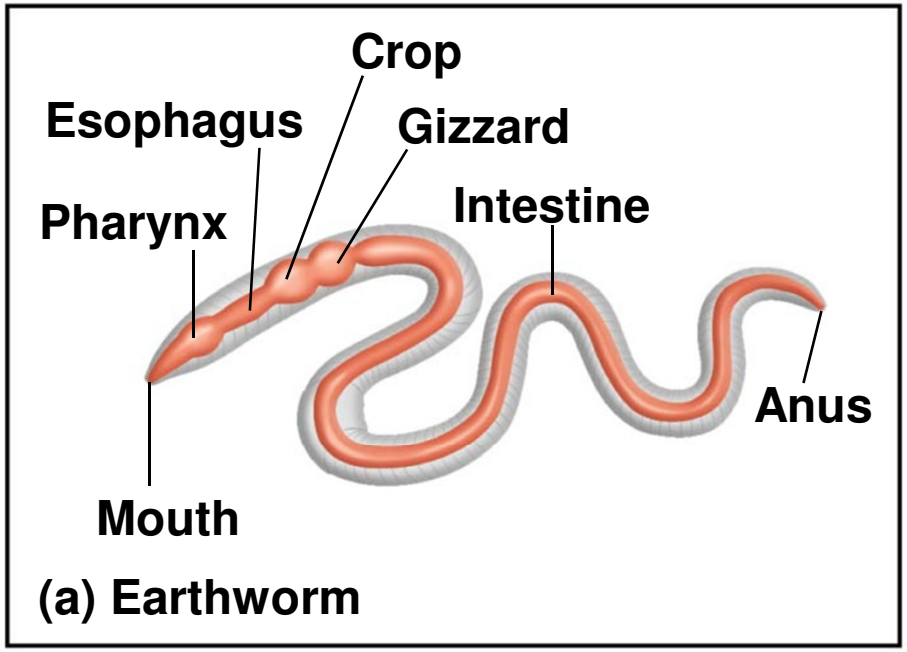
Figure 33.6

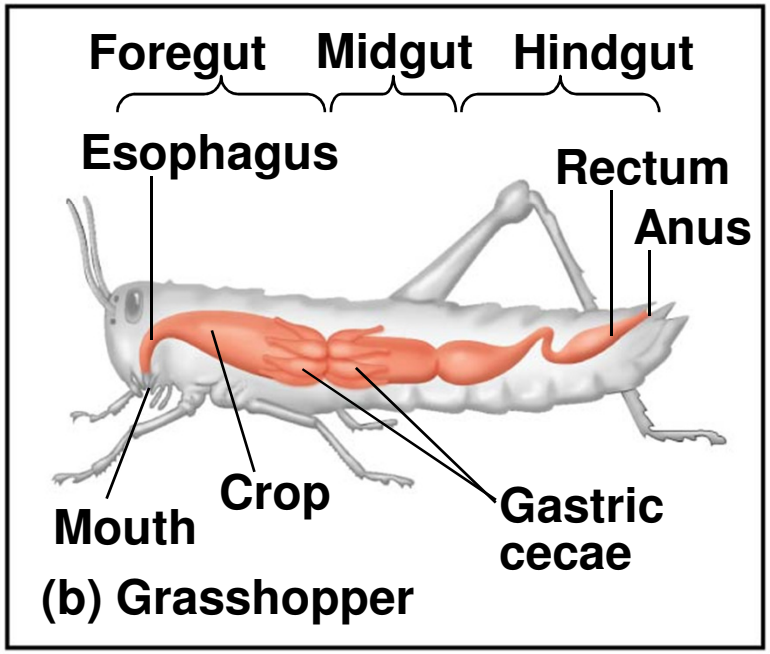

Mouth
Tentacles
Food
1 Digestive enzymes released
2 Food particles broken down
3 Food particles engulfed and digested
Epidermis
Gastrodermis

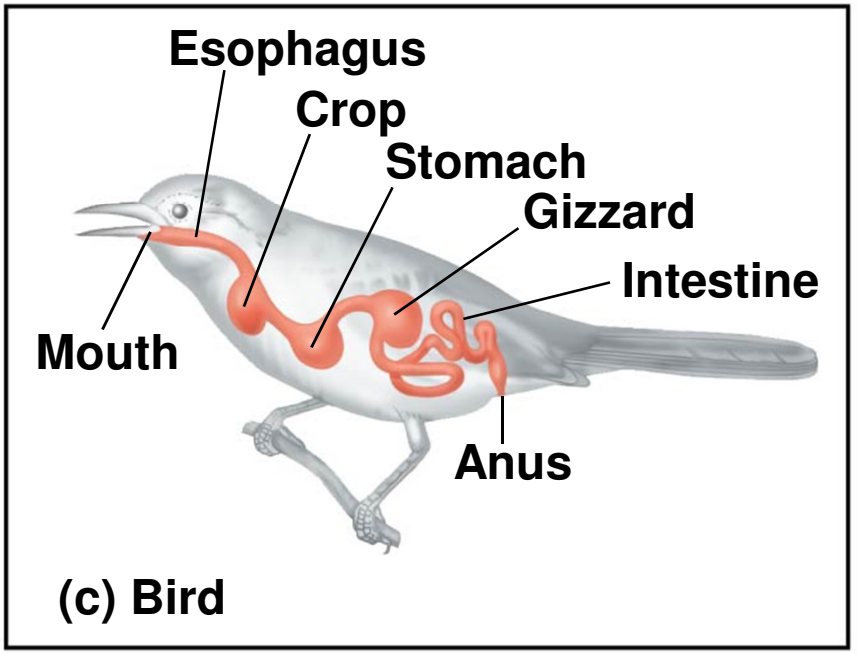


Video: Hydra Eating

Figure 33.7


Crop
Esophagus
Gizzard
Pharynx
Intestine
Anus
Mouth
(a) Earthworm

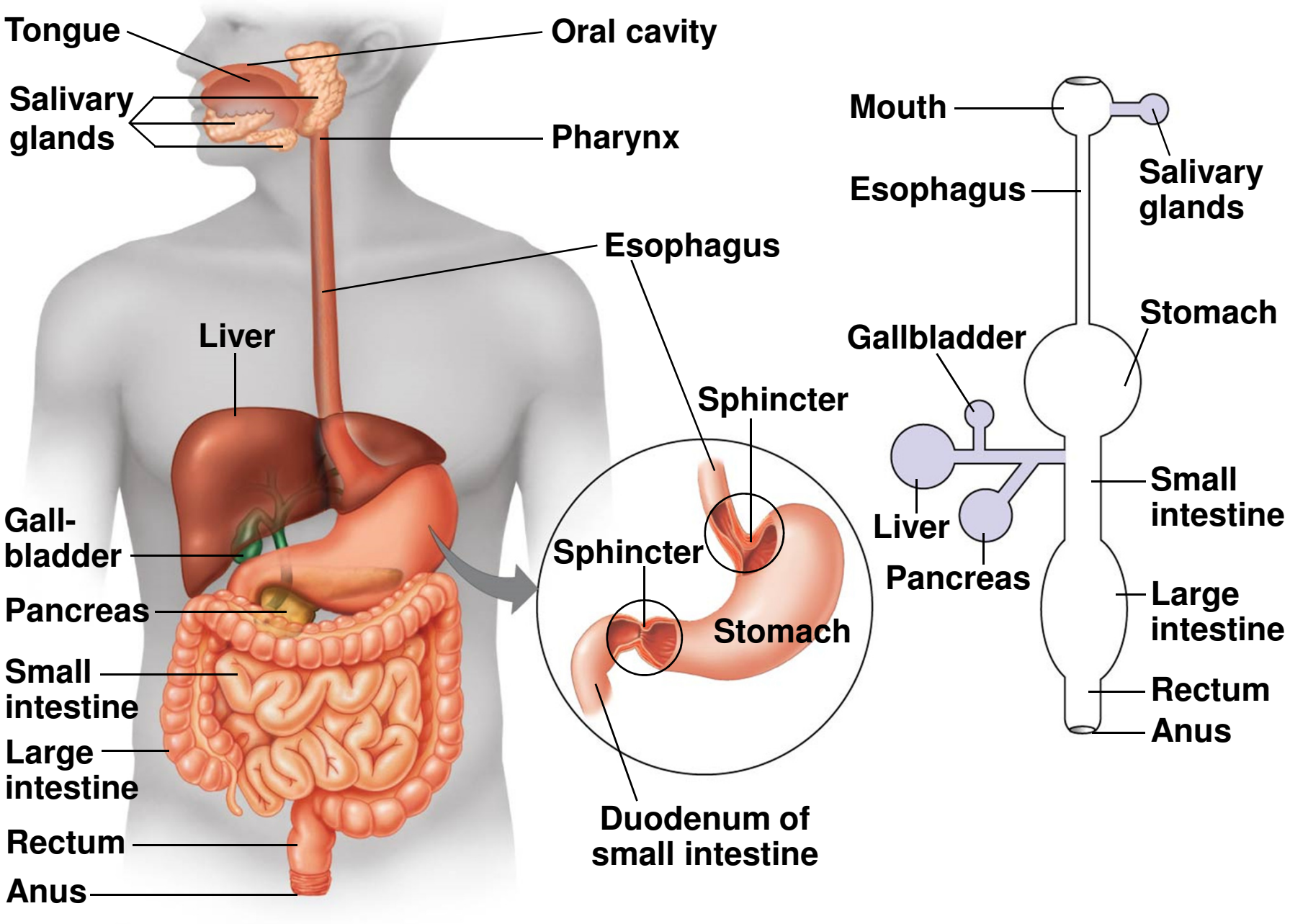

Foregut
Midgut
Hindgut
Esophagus
Rectum
Anus
Mouth
Crop
Gastric cecae
(b) Grasshopper


Esophagus
Crop
Stomach
Gizzard
Intestine
Mouth
Anus
(c) Bird

Concept 33.3: Organs specialized for sequential stages of food processing form the mammalian digestive system

- The mammalian digestive system consists of an alimentary canal and accessory glands that secrete digestive juices through ducts
- Mammalian accessory glands are the
  - Salivary glands
  - Pancreas
  - Liver
  - Gallbladder

Figure 33.8


Tongue
Oral cavity
Salivary glands
Pharynx
Esophagus
Liver
Gall-bladder
Pancreas
Small intestine
Large intestine
Rectum
Anus
Sphincter
Sphincter
Stomach
Duodenum of small intestine
Mouth
Esophagus
Salivary glands
Stomach
Gallbladder
Small intestine
Liver
Pancreas
Large intestine
Rectum
Anus

- Food is pushed along by **peristalsis**
  - Rhythmic contractions of muscles in the wall of the canal
- Valves called **sphincters** regulate the movement of material between compartments

The Oral Cavity, Pharynx, and Esophagus

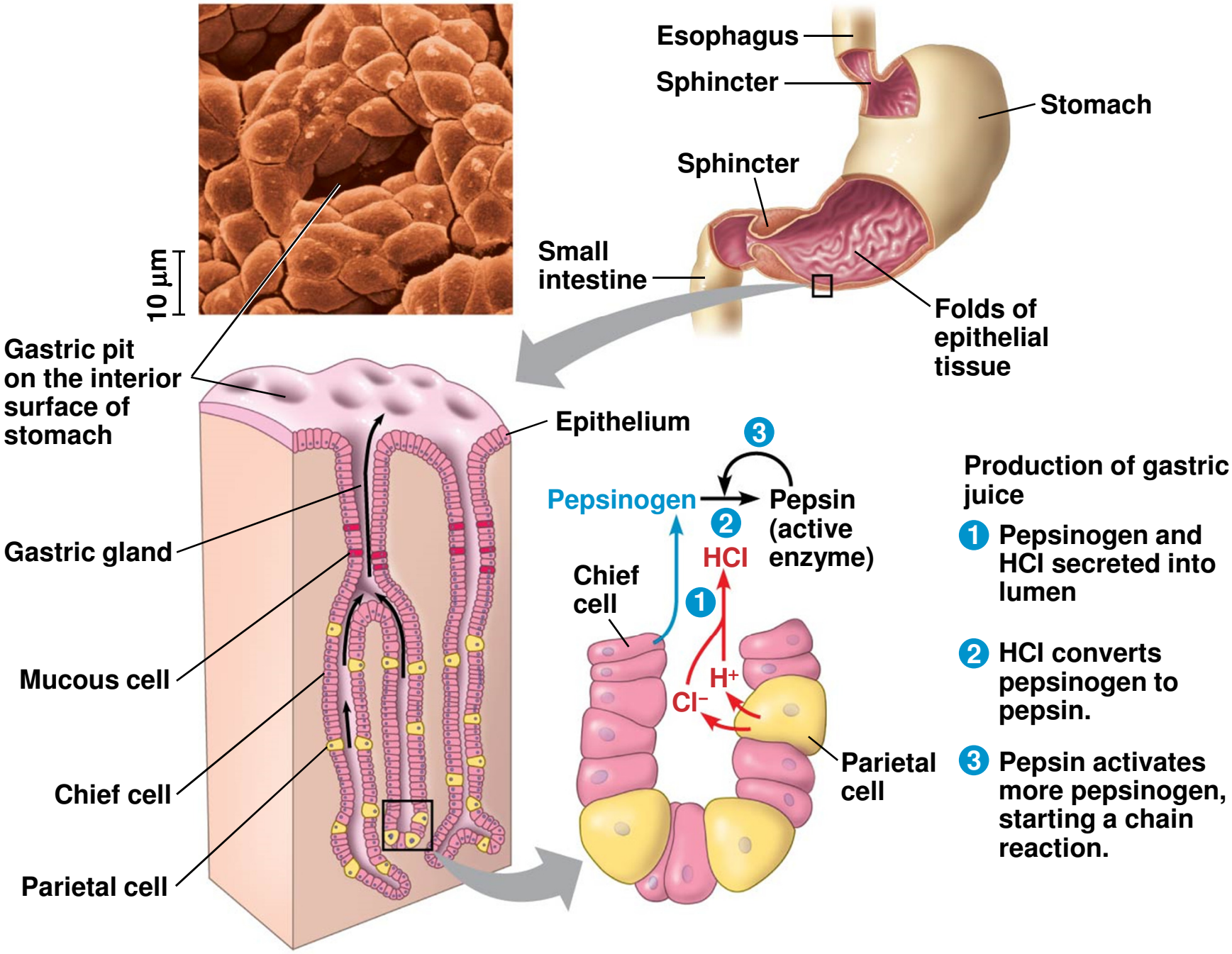
- The first stage of digestion is mechanical and takes place in the **oral cavity**
  - Teeth chew food into smaller particles, increasing its surface area
- **Salivary glands** deliver saliva to the oral cavity through duct, initiating chemical digestion
  - Food is exposed to the salivary enzyme **amylase**, initiating breakdown of glucose polymers
  - Saliva also contains **mucus**, a viscous mixture of water, salts, cells, and glycoproteins

- The tongue shapes food into a **bolus** and provides help with swallowing
- The throat, or **pharynx**, is the junction that opens to both the esophagus and the trachea
  - The **esophagus** connects to the stomach
  - The trachea (windpipe) leads to the lungs

Digestion in the Stomach

- The **stomach** stores food and begins digestion of proteins
  - Secretes **gastric juice**, which converts a meal to a mixture of food and digestive juice called **chyme**

Figure 33.9


10 µm
Esophagus
Sphincter
Stomach
Sphincter
Small intestine
Folds of epithelial tissue
Gastric pit on the interior surface of stomach
Epithelium
Gastric gland
Mucous cell
Chief cell
Parietal cell
3
Pepsinogen
Pepsin (active enzyme)
2
HCl
Chief cell
1
H+
Cl−
Parietal cell
Production of gastric juice
1 Pepsinogen and HCl secreted into lumen
2 HCl converts pepsinogen to pepsin.
3 Pepsin activates more pepsinogen, starting a chain reaction.

Chemical Digestion in the Stomach

- Gastric juice has a low pH of about 2, which kills bacteria and denatures proteins
- Gastric juice is made up of hydrochloric acid (HCl) and **pepsin**
  - Pepsin is a **protease**, or protein-digesting enzyme, that cleaves proteins into smaller peptides
  - Works best in strongly acidic environments (unlike most other enzymes)
- Mucus protects the stomach lining from gastric juice

Stomach Dynamics

- Coordinated contraction and relaxation of stomach muscle churn the stomach's contents
- Sphincters prevent chyme from entering the esophagus and regulate its entry into the small intestine
- Stomach contents typically pass into the small intestine 2–6 hours after a meal

Digestion in the Small Intestine

- The **small intestine** is the longest section of the alimentary canal
  - The major organ of digestion and absorption!
- The first portion of the small intestine is the **duodenum**
  - Here, chyme from the stomach mixes with digestive juices from the pancreas, liver, gallbladder, and the intestinal wall
  - Most digestion occurs in the duodenum
    - The *jejunum* and *ileum* function mainly in absorption of nutrients and water

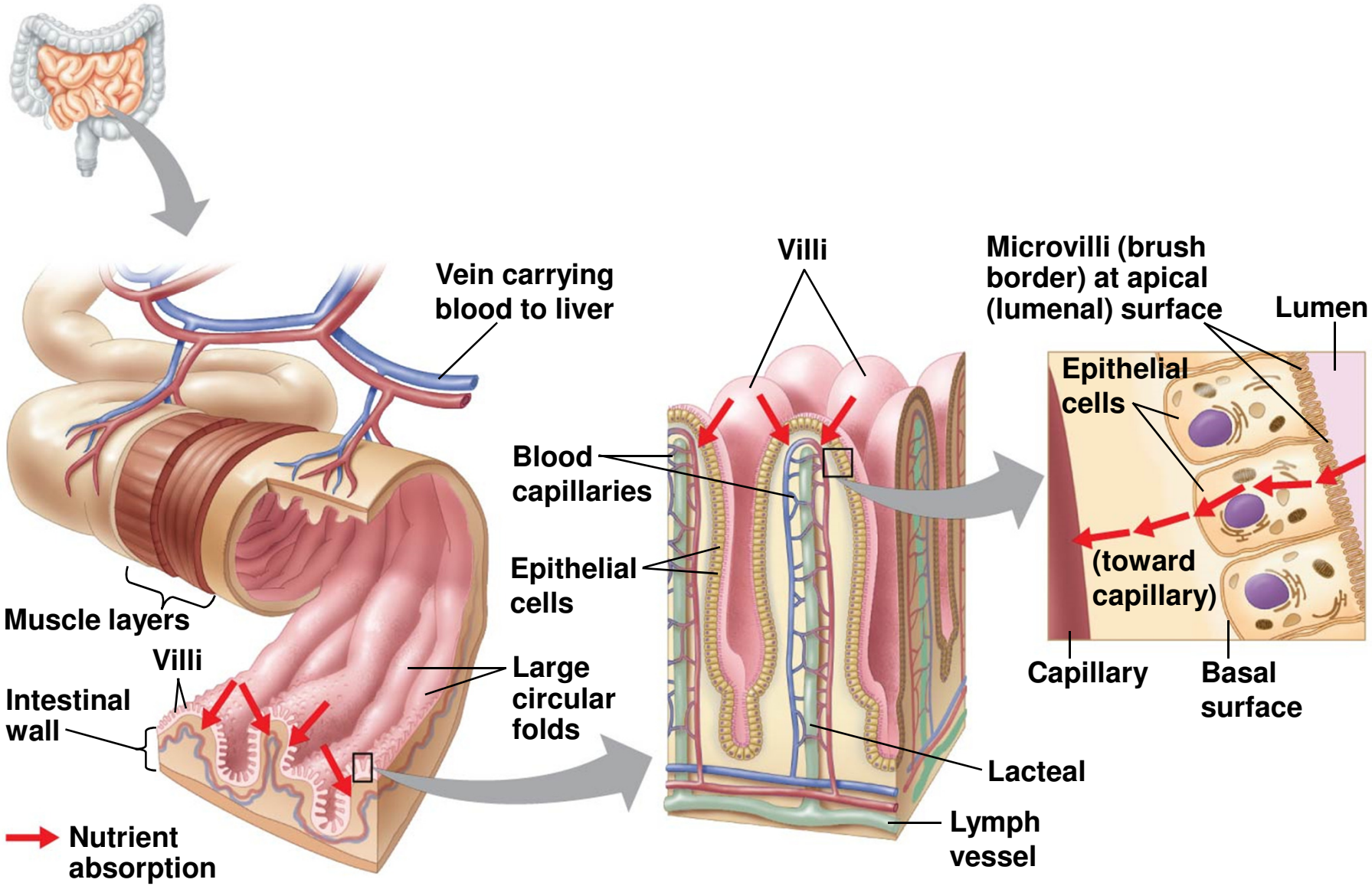
Pancreatic Secretions and Bile Production by the Liver

- The **pancreas** aids in chemical digestion by producing an alkaline solution and several enzymes
  - Neutralizes the acidic chime and acts as a buffer
- In the small intestine, **bile** aids in digestion and absorption of fats
  - Bile is made in the **liver** and stored in the **gallbladder**
  - Bile also destroys nonfunctional red blood cells

Absorption in the Small Intestine

- The small intestine has a huge surface area
  - Due to **villi** and **microvilli** that project into the intestinal lumen
  - The enormous microvillar surface creates a brush border that greatly increases the rate of nutrient absorption
- The **hepatic portal vein** carries nutrient-rich blood from the capillaries of the villi to the liver, then to the heart
- The liver regulates nutrient distribution, interconverts many organic molecules, and detoxifies many organic molecules

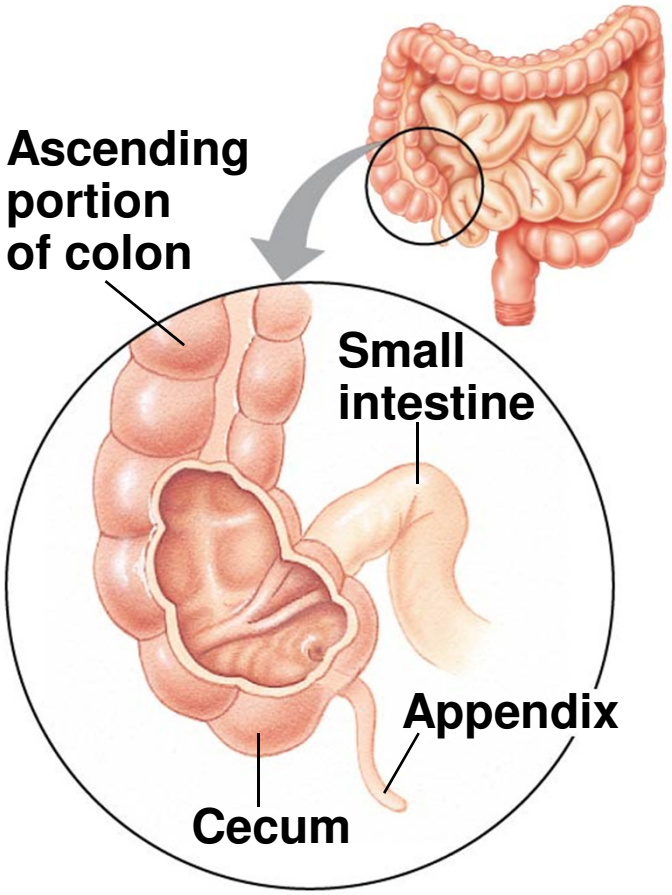
Figure 33.11


Vein carrying blood to liver
Villi
Microvilli (brush border) at apical (lumenal) surface
Lumen
Epithelial cells
Blood capillaries
Epithelial cells
(toward capillary)
Muscle layers
Villi
Intestinal wall
Large circular folds
Capillary
Basal surface
Lacteal
Lymph vessel
Nutrient absorption

Absorption in the Large Intestine

- The alimentary canal ends with the **large intestine**, which includes the colon, cecum, and rectum
- The small intestine connects to the large intestine at a T-shaped junction
  - One arm of the “T” is the **colon**
    - Leads to the rectum and anus
  - The other arm is a pouch called the **cecum**
    - Aids in the fermentation of plant material
    - Has an extension called the **appendix**
      - Plays a very minor role in immunity

Figure 33.13

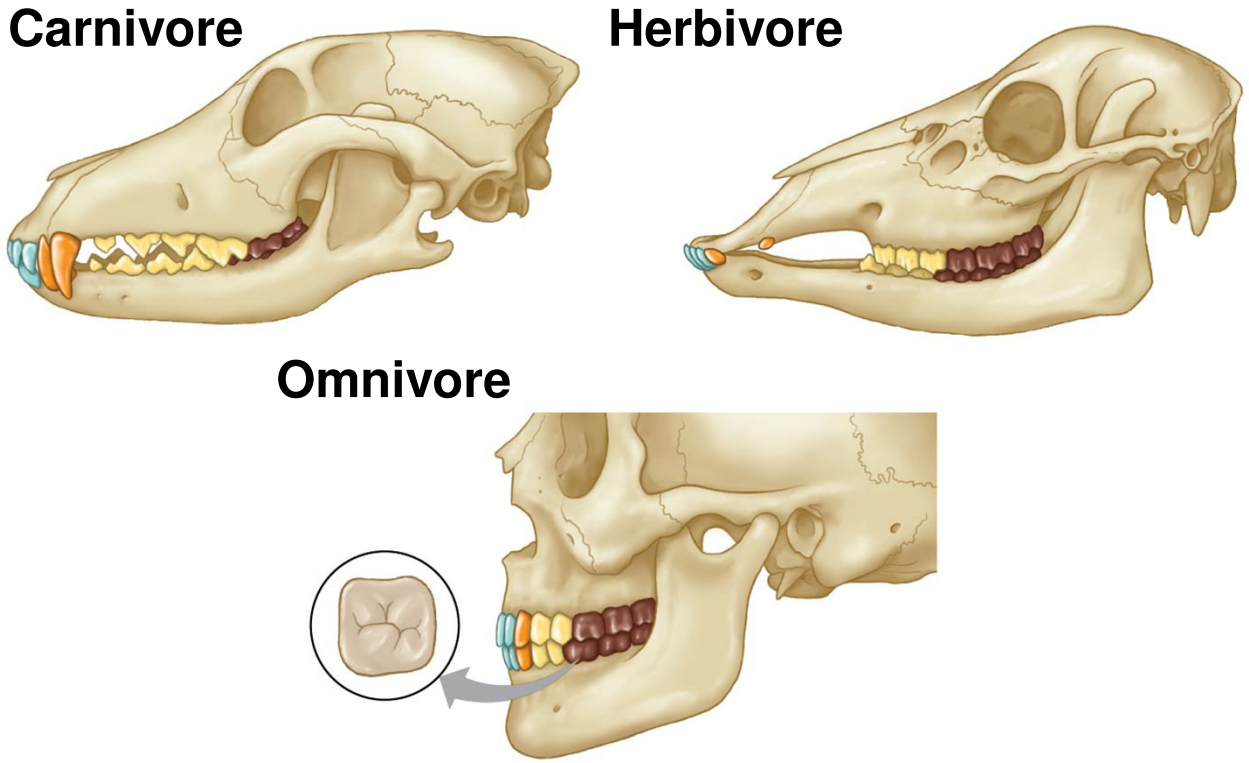


Junction of the small and large intestines

- A major function of the colon is to recover water that has entered the alimentary canal
- The colon houses bacteria (e.g., *Escherichia coli*) that live on unabsorbed organic material
  - Some produce vitamins
- The wastes of the digestive system, or **feces**, become more solid as they move through the colon
  - Includes undigested material and bacteria
- Feces are stored in the **rectum** until they can be eliminated through the anus
- Two sphincters between the rectum and anus control bowel movements

Concept 33.4: Evolutionary adaptations of vertebrate digestive systems correlate with diet

- Digestive systems of vertebrates are variations on a common plan
- However, there are intriguing adaptations, often related to diet

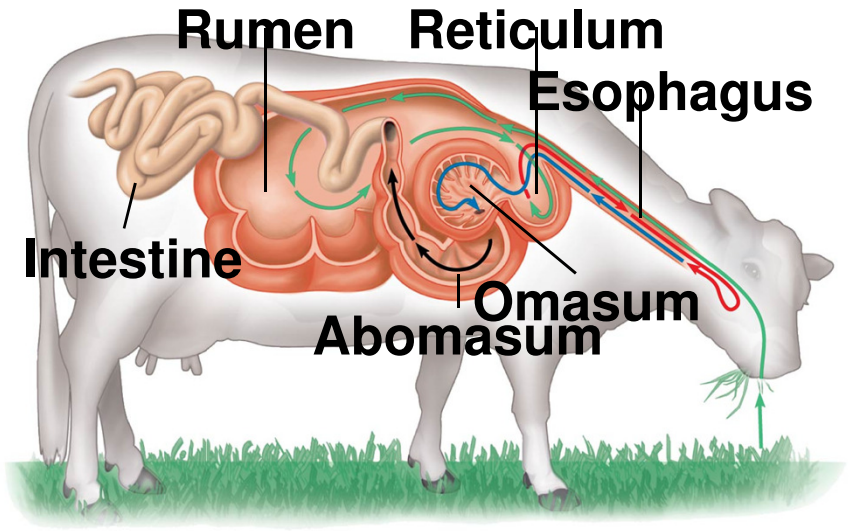


Dental Adaptations

- Dentition, an animal's assortment of teeth, is one example of structural variation reflecting diet
  - Carnivores: Pointed incisors and canines
  - Herbivores: Premolars and molars with broad, ridged surfaces that grind
  - Omnivore: Incisors for biting, canines for tearing, premolars for grinding, molars for crushing
- The success of mammals is due in part to their dentition, which is specialized for different diets
- Nonmammalian vertebrates have less specialized teeth, though exceptions exist
  - For example, the teeth of poisonous snakes are modified as fangs for injecting venom

Mutualistic Adaptations

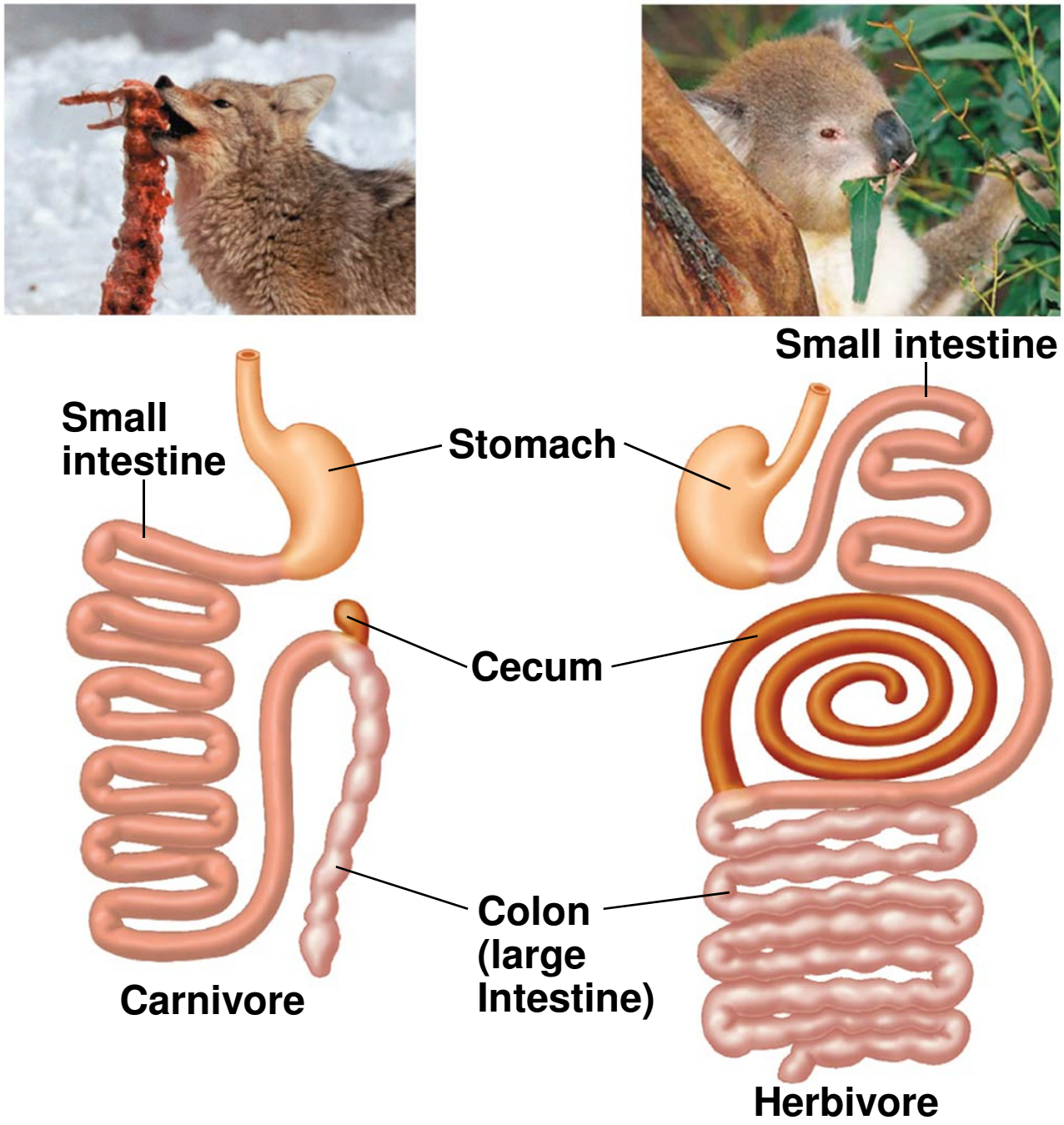
- Microorganisms help herbivores digest plants
  - Many herbivores have fermentation chambers in their alimentary canals, where mutualistic microorganisms digest cellulose
- The most elaborate adaptations for an herbivorous diet have evolved in the animals called **ruminants**
  - Includes deer, sheep, and cattle



Stomach and Intestinal Adaptations

- Many carnivores have large, expandable stomachs
- Herbivores and omnivores generally have longer alimentary canals than carnivores
  - Reflects the longer time needed to digest vegetation

Figure 33.16


Small intestine
Small intestine
Stomach
Stomach
Cecum
Cecum
Colon (large Intestine)
Colon (large Intestine)
Carnivore
Herbivore

Concept 33.5: Feedback circuits regulate digestion, energy allocation, and appetite

- An animal's intake of food and use of nutrients are matched to circumstance and need

Regulation of Digestion

- Each step in the digestive system is activated as needed
- The *enteric division* of the nervous system helps to regulate the digestive process
- The endocrine system also regulates digestion through the release and transport of hormones

Energy Allocation

- The flow and transformation of energy in an animal determine nutritional needs
  - Called **bioenergetics**
- An animal's energy use per unit of time is called its **metabolic rate**
- Metabolic rate can be determined by monitoring
  - An animal's rate of heat loss
  - The amount of O_2 consumed
  - The amount of CO_2 produced

Minimum Metabolic Rate

- Animals must maintain a minimum metabolic rate for basic cell functions
- *Basal metabolic rate, BMR*, is the minimum metabolic rate of a nongrowing endotherm that is at rest, has an empty stomach, and is not experiencing stress
- The metabolic rate of a fasting, nonstressed ectotherm at a particular temperature is called *standard metabolic rate, SMR*
- Endothermy is more energetically costly than ectothermy
  - BMR of endotherms is much higher than SMR of ectotherms!
- For ectotherms and endotherms, activity greatly affects metabolic rate

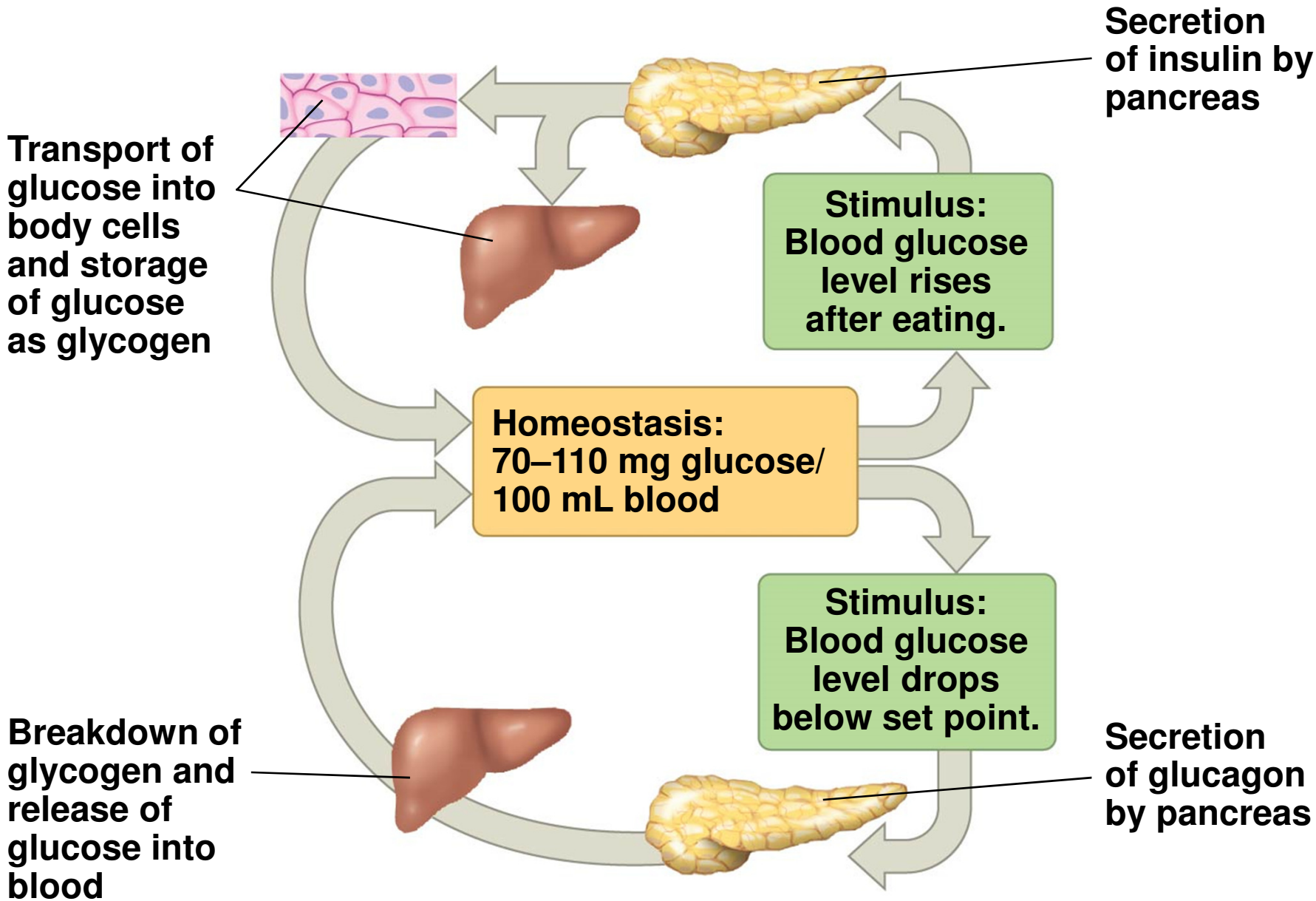
Regulation of Energy Storage

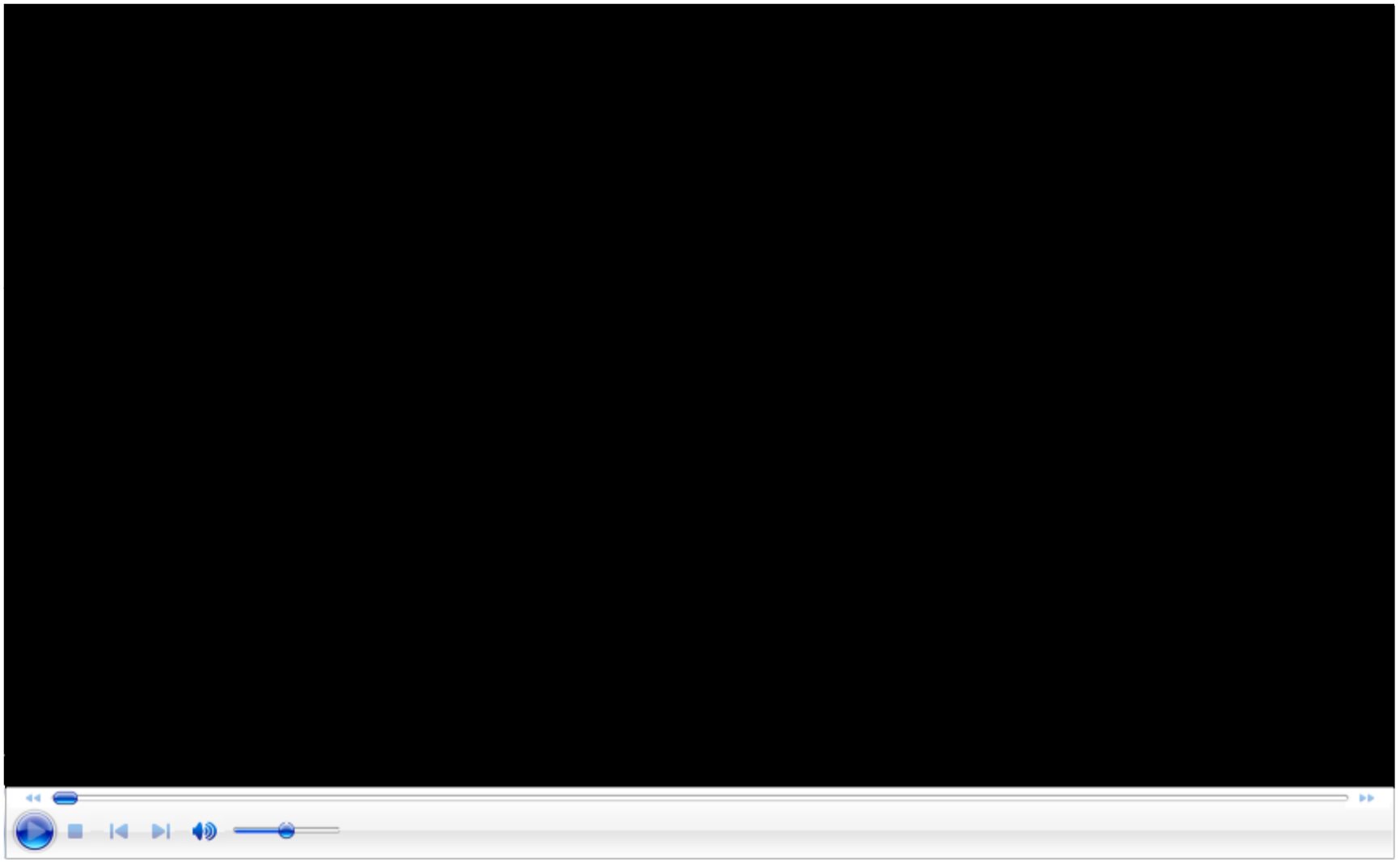
- When an animal takes in more energy than is needed for metabolism and activity, excess energy is stored
  - In humans, the liver and muscle cells are used first
    - Energy is stored as glycogen
    - When glycogen depots are full, additional excess energy is stored as fat in adipose cells
- When fewer calories are taken in than expended, the body expends liver glycogen, muscle glycogen, and then fat, in that order

Glucose Homeostasis

- Insulin and glucagon together maintain glucose levels
  - Regulate synthesis and breakdown of glycogen
- Insulin levels rise after a carbohydrate-rich meal
  - Glucose entering the liver is used to synthesize glycogen
- Between means, glucose concentration drops
  - Glucagon stimulates the liver to break down glycogen and release glucose into the blood
- Insulin and glucagon are produced in the pancreas
  - *Beta cells* make insulin
  - *Alpha cells* make glucagon

Figure 33.19


Secretion of insulin by pancreas
Transport of glucose into body cells and storage of glucose as glycogen
Stimulus: Blood glucose level rises after eating.
Homeostasis: 70–110 mg glucose/ 100 mL blood
Stimulus: Blood glucose level drops below set point.
Breakdown of glycogen and release of glucose into blood
Secretion of glucagon by pancreas



Video: Homeostasis

Diabetes Mellitus

- Diabetes mellitus is a disease caused by a deficiency of insulin or a decreased response to insulin in target tissues
- Cells are unable to take up glucose to meet their metabolic needs
- Fat becomes the main substrate for cellular respiration

- Type 1 diabetes is an autoimmune disorder in which the immune system destroys the pancreatic beta cells
  - Treatment consists of insulin injections
- Type 2 diabetes is characterized by a failure of target cells to respond normally to insulin
  - Heredity is a factor
  - Excess body weight and lack of exercise increase the risk

Regulation of Appetite and Consumption

- *Overnourishment* causes obesity, which results from excessive intake of food energy with the excess stored as fat
  - Obesity contributes to diabetes (type 2), cancer of the colon and breasts, heart attacks, and strokes